

## C0 IR Accelerator Physics (WBS 2.13.2)

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## Scope of WBS 2.13.2

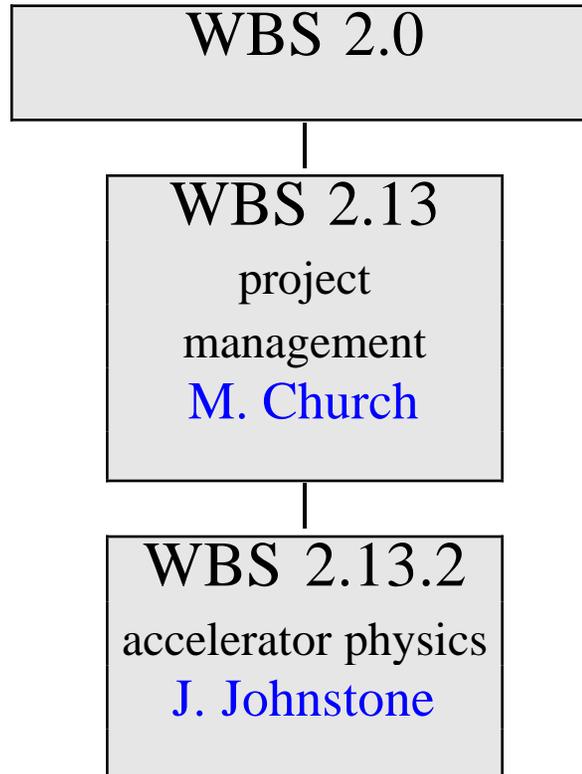
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- Design, and validate, the C0 Interaction Region accelerator parameters:
  - IR design meets BTeV experimental needs
  - consistency with existing technology & hardware
  - minimally impacts nominal Tevatron operating parameters

- Management Structure
  - IR Design - performance summary & components
  - Optics - injection & collision
  - Beam separation & collisions
  - Correction elements & error compensation schemes
  - Tune footprints & dynamic aperture
  - Beam halo & collimation
  - Ongoing AP studies
  - Summary
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# AP Organization

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Features:

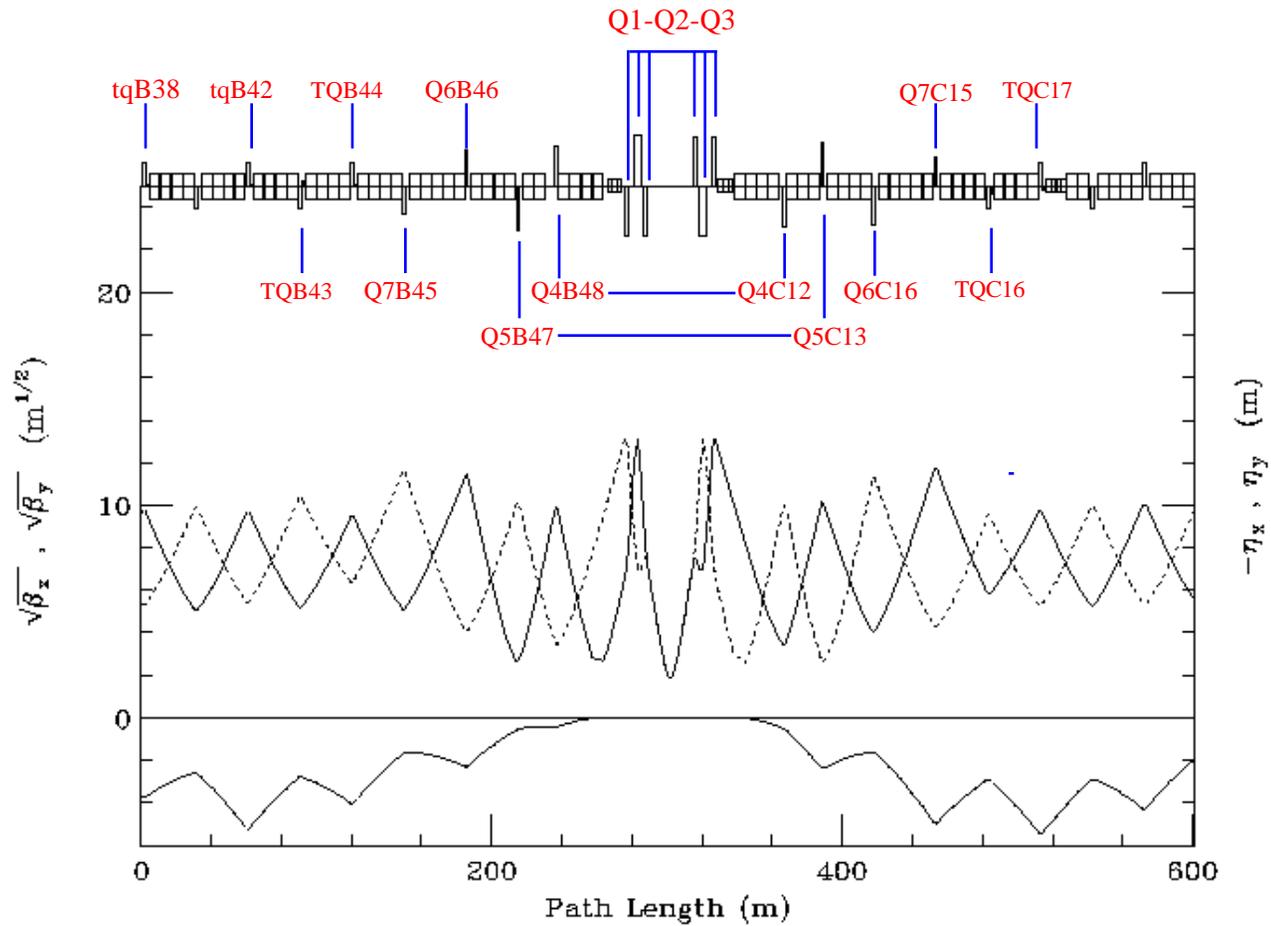
- $\beta^* = 0.35$  m
- Triplet low- $\beta$  optics add **1 integer** of tune in each plane
  - C0 IR is transparent to the rest of Tevatron.

Operational Modes:

Baseline design accommodates 2 low- $\beta^*$  collision options:

- Full luminosity at C0 [ $\beta^* = 0.35$  m] & separated beams at B0/D0 [ $\beta^* = 1.65$  m], and;
- No collisions at C0 [ $\beta^* = 3.50$  m], and design luminosity at B0/D0 [ $\beta^* = 0.35$  m].

# C0 IR Layout



(Injection optics shown)

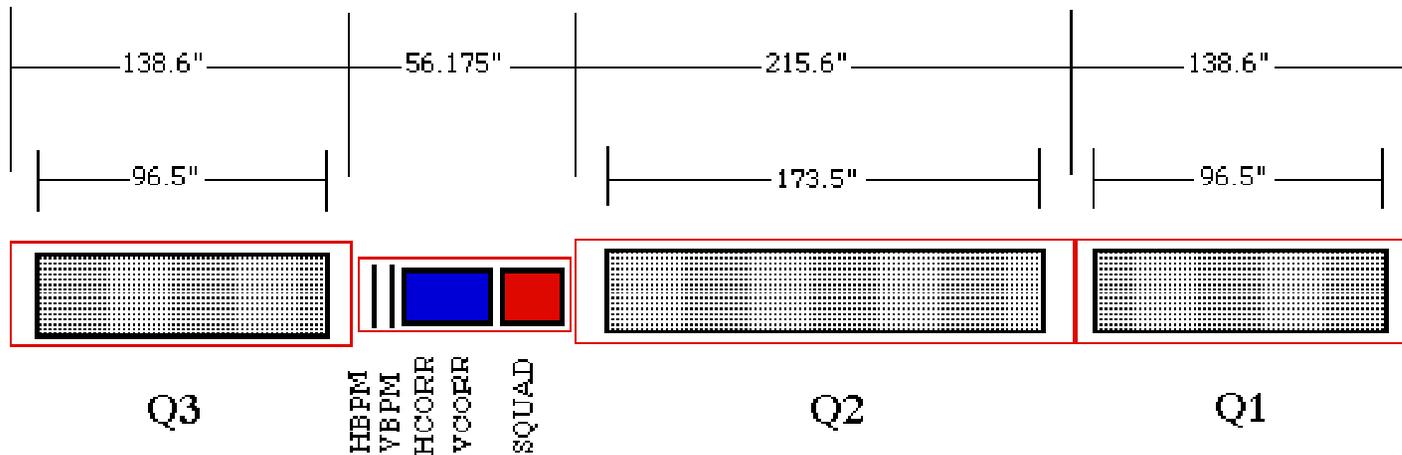
Major Magnets:

- Q1→Q5 : New, LHC-like 170 T/m quads @ 9560A.
- Q6, Q7 : Re-cycled, 54" 140 T/m LBQ's from B0/D0 (*plus* associated power P-spools).
- TB43/44 & TC16/17 : New, 25 T-m/m quadrupole spools.

New Spools:

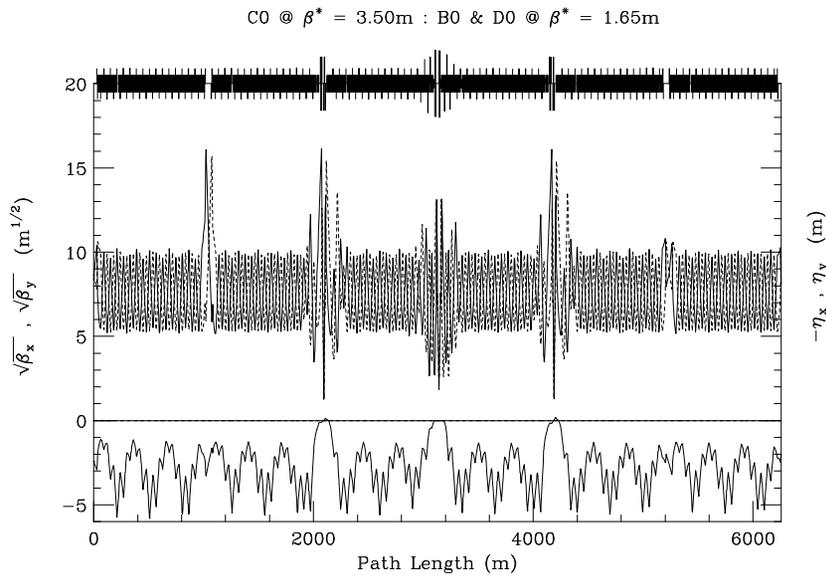
- 10 spools in 3 styles — 8 in arcs & 2 in triplets:
  - arc spools have mixtures of HD & VD, SF & SD, HBPM & VBPM, and strong trim quads.
  - triplet spools contain HD + VD, SQ, HBPM + VBPM.

## Triplet Spool Package:



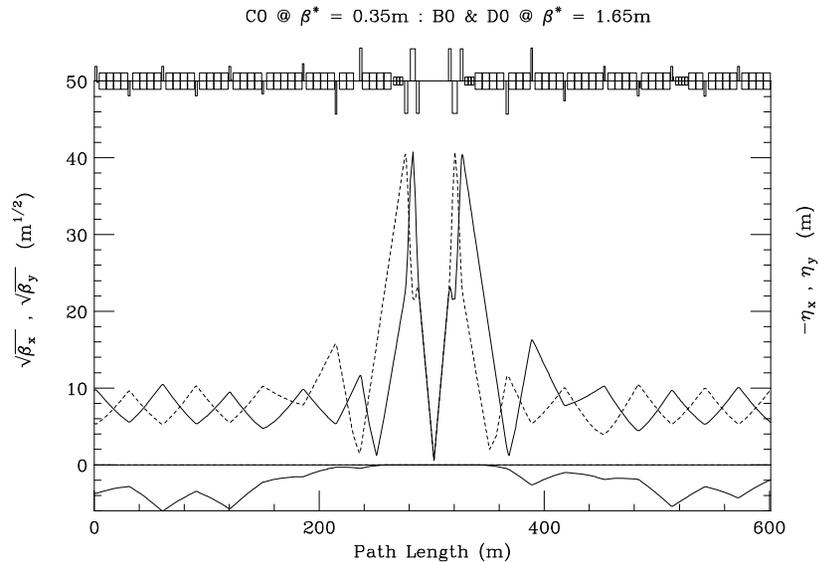
- $\beta_x = \beta_y > 60\%$  of  $\beta_{max}$  between Q2 & Q3:
  - HCORR & VCORR are 90° from the IP for position control.
  - With 0° across the triplet, SQUAD is perfect for roll correction.

# C0 Injection Optics



C0 @ $\beta^* = 3.50\text{m}$ : B0/D0 @ $\beta^* = 1.65\text{m}$					
1 TeV/c Injection					
	Gradient (T/m)	Current (A)		Gradient (T/m)	Current (A)
Q1D	-164.783	9267	Q1F	164.783	9267
Q2F	168.814	9493	Q2D	-168.814	9493
Q3D	-164.783	9267	Q3F	164.783	9267
Q4B48	133.019	7480	Q4C12	-133.019	7480
Q5B47	-145.047	8157	Q5C13	145.047	8157
Q6B46	117.055	4045	Q6C14	-122.786	4248
Q7B45	-92.551	3198	Q7C15	92.940	3211
TB44	4.939	5.02	TC16	-25.569	25.98
TB43	17.724	18.01	TC17	-10.470	10.64
tB42	6.793	34.51			
tB39	0				
tB38	3.013	15.31			

# C0 Collision Optics



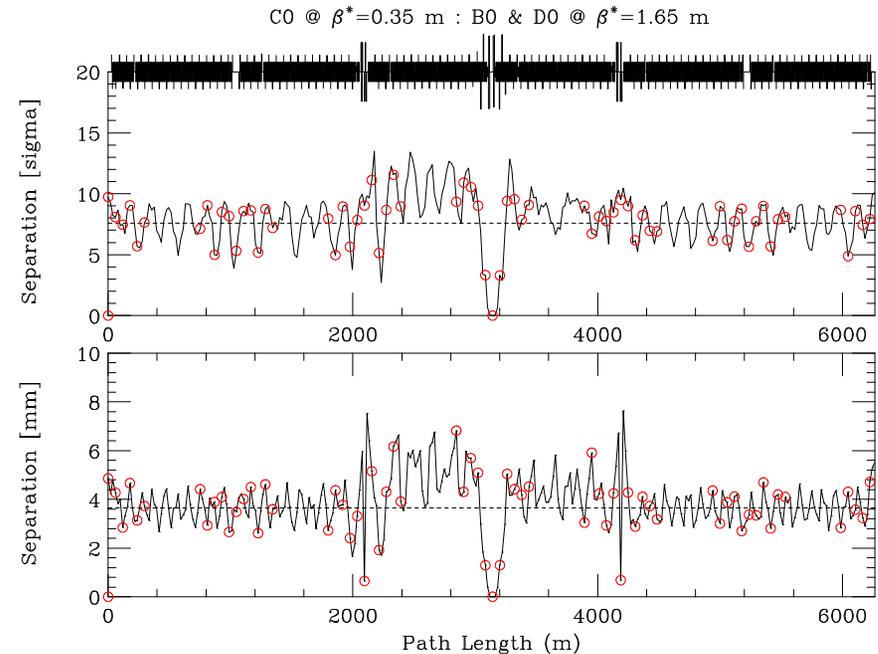
$\beta^* = 0.35\text{ m} : \text{B0/D0 @ } \beta^* = 1.65\text{ m}$					
<b>C0 Collisions 1 TeV/c</b>					
	Gradient (T/m)	Current (A)		Gradient (T/m)	Current (A)
Q1D	-169.228	9517	Q1F	169.228	9517
Q2F	165.397	9301	Q2D	-165.397	9301
Q3D	-169.228	9517	Q3F	169.228	9517
Q4B48	169.688	9524	Q4C12	-169.688	9524
Q5B47	-168.875	9497	Q5C13	168.875	9497
Q6B46	91.625	3166	Q6C14	-101.95	3523
Q7B45	-66.539	2299	Q7C15	76.322	2637
TB44	9.528	9.68	TC16	-35.373	35.94
TB43	-0.819	0.83	TC17	22.589	22.95
tB42	-0.844	4.29			
tB39	0				
tB38	-7.424	37.71			

# C0 Collision Helix

- Electrostatic separators bring beams into collision.

C0 @  $\beta^* = 0.35$  m : B0/D0 @  $\beta^* = 1.65$  m  
 1 TeV/c :  $\epsilon_N = 20\pi \mu\text{m}$  &  $\sigma_p/p = 1.5\text{E-}4$

Horizontal			Vertical		
	#	kV/cm		#	kV/cm
A49	1	0.0	A49	2	25.744
B11	2	0.0	B11	1	-25.744
B17	4	18.112			
B49	2	-40.000	B49	1	-40.000
C11	1	40.000	C11	2	40.000
			C17	4	-20.355
C49	1	13.486	C49	2	0.0
D11	2	-13.486	D11	1	0.0
D48	1	0.0			
			A17	1	0.0



- Average ring-wide separation is  $\sim 8\sigma$ , which could be increased with a larger sub-set of separators.

## C0 Correction Elements

	C0 Run II	D0	C0 IR
HD	8	10	<b>13</b>
VD	8	9	<b>13</b>
QF/QD	10	0	0
SQ	5	2	7
SF/SD	10	8	4
NS (other)	0	2	0
SS	2	0	0
O	1	0	0

- Unremarkable Changes:

- QF & QD: Tune quad functions absorbed by IR quads.
- D0 sextupoles are special elements in feeddown circuits.
- C0 Run II octupole is a fixed- target slow-spill element.

- Remarkable Changes:

- 3 SF + 3 SD chromatic sextupoles are lost in the C0 Run II → BTeV IR conversion.
- C0 feeddown skew sextupoles are gone from B43 & B47 in the IR lattice.

# Chromatic Compensation

- Smaller IR dispersion reduces effectiveness of 6 inner chromatic sextupoles.
- Loss of 6 sextupoles is a small perturbation to the remaining 170 elements in the circuits.

C0 / BTeV				C0 / Run II		
Site	$\beta_x$	$\beta_y$	$\eta_x$	$\beta_x$	$\beta_y$	$\eta_x$
B43	29.8	100	3.57	30.6	93.7	3.52
B44	84.6	32.3	5.54	95.2	30.8	5.57
B45	23.1	103	<b>2.22</b>	31.3	94.5	<b>2.73</b>
B46	92.9	66.6	<b>1.48</b>	93.5	31.4	<b>3.45</b>
B47	33.4	211	<b>0.32</b>	30.2	95.2	<b>1.47</b>
B48						
B49						
C0	0.35	0.35	<b>0.0</b>	70.8	71.9	<b>1.98</b>
C11						
C12						
C13	253	30.6	<b>1.43</b>	94.8	31.4	<b>2.02</b>
C14	59.9	95.7	<b>1.03</b>	30.8	96.1	<b>1.77</b>
C15	99.0	17.0	<b>1.88</b>	92.5	31.3	<b>3.94</b>
C16	20.6	104	2.08	30.5	93.4	3.07
C17	90.1	29.7	5.32	93.9	30.7	5.79

C0 Run II		C0 IR	
$Q'_x = Q'_y = 0 @ 1 \text{ TeV}/c$			
SF(88)	SD(88)	SF(85)	SD(85)
(T-m/m <sup>2</sup> )		(T-m/m <sup>2</sup> )	
B0/D0 : $\beta^* = 1.65\text{m}$		B0/D0 : $\beta^* = 1.65\text{m}$	
		C0 : $\beta^* = 3.50\text{m}$	
58.2	-95.7	67.3	-110.5
B0/D0 : $\beta^* = 0.35\text{m}$		B0/D0 : $\beta^* = 0.35\text{m}$	
		C0 : $\beta^* = 3.50\text{m}$	
111.0	-178.4	121.7	-195.1
		B0/D0 : $\beta^* = 1.65\text{m}$	
		C0 : $\beta^* = 0.35\text{m}$	
		115.6	-191.7

## Feeddown Sextupole Circuits

- 49 normal & skew sextupoles, in 8 families, control differential coupling & tunes. For 150 GeV/c helix:

$$\begin{pmatrix} S_1 \\ S_2 \\ S_3 \\ S_{7+8} \end{pmatrix} = \begin{pmatrix} -.1207 & -.0406 & -.0173 & -.0765 \\ .0466 & .1361 & .0044 & .0104 \\ .0109 & .0176 & .0956 & -.0109 \\ -.0078 & -.0085 & -.3176 & -.7624 \end{pmatrix} \bullet \begin{pmatrix} \Delta v_x \\ \Delta v_y \\ \Delta C_{sq} \\ \Delta S_{sq} \end{pmatrix}$$

- Dropping B43 & B47 still leaves 10 S2 circuit members:

$$\begin{pmatrix} S_1 \\ S_2 \\ S_3 \\ S_{7+8} \end{pmatrix} = \begin{pmatrix} -.1213 & -.0426 & -.0173 & -.0767 \\ .0547 & .1598 & .0052 & .0122 \\ .0088 & .0114 & .0954 & -.0114 \\ -.0107 & -.0171 & -.3179 & -.7631 \end{pmatrix} \bullet \begin{pmatrix} \Delta v_x \\ \Delta v_y \\ \Delta C_{sq} \\ \Delta S_{sq} \end{pmatrix}$$

- Losing B43 & B47 SS  $\Rightarrow$  ~17% increase in S2 current.

## Position Control at the IP

	X* COEFFICIENTS		Y* COEFFICIENTS	
	(a)	(b)	(a)	(b)
B45			-0.0706	-0.0052
B46	-0.0861	+0.5043		
B47				
B48				
B49		+1.0 $\theta$		-0.3881
C0U	+0.9882		+1.0 $\theta$	
C0	$X^* = 19.1 \theta$	$7.3 \theta$	$Y^* = 18.4 \theta$	$6.8 \theta$
C0D	+1.0 $\theta$		+0.9043	
C12				+1.0 $\theta$
C13		-0.5461		
C14			-0.0818	+0.2622
C15	-0.0686	-0.4359		

- $\theta_{\max} = 144 \mu\text{r}$ ,  $\beta_{\text{corr}} > 1000 \text{ m}$  for  $\beta^* = 0.35 \text{ m}$ , (a) adjusts position at the IP by  $\pm 2.75 \text{ mm}$  — 3x the range of B0/D0.
- Triplet trim dipoles can correct systematic transverse displacements of  $\pm 0.5 \text{ mm}$  and random errors of  $\pm 0.25 \text{ mm}$ .

## Angle Control at the IP

	X'* COEFFICIENTS		Y'* COEFFICIENTS	
	(a)	(b)	(a)	(b)
B45			+1.0 $\theta$	+1.0 $\theta$
B46	-0.6812	+0.8620		
B47				-0.6505
B48		-0.5443		
B49				
C0U	-0.1467		+0.3003	
C0	X'*= 7.8 $\theta$	11.2 $\theta$	Y'*= 7.6 $\theta$	11.4 $\theta$
C0D	+0.2772		-0.1336	
C12				+0.6029
C13		+0.5708		
C14			+0.6419	-0.8284
C15	+1.0 $\theta$	+1.0 $\theta$		

- Angle control at the IP is aperture limited —  $\pm 1.0$  mrad in solutions (a) and (b) corresponds to beams offset by 25 mm in the triplet quads.

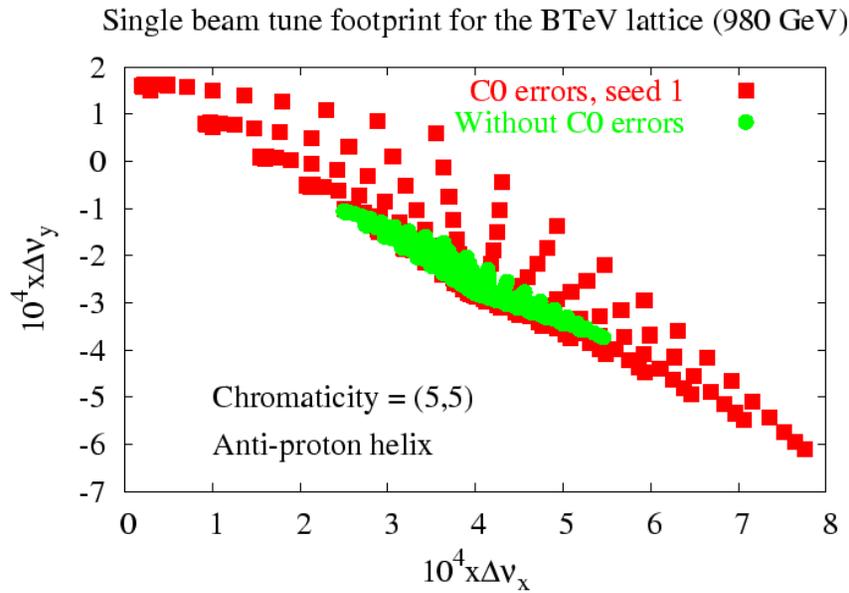
## Triplet Roll Error Compensation

Spool	$\beta_x$ (m)	$\beta_y$ (m)	$2\pi (\mu_x - \mu_y)$ (deg °)	$\sqrt{\beta_x\beta_y} \cdot \cos(\Delta\mu)$ (m)	$\sqrt{\beta_x\beta_y} \cdot \sin(\Delta\mu)$ (m)
PACKB45	23.1	102.7	-65.45	20.239	-44.303
PACKB46	92.9	66.6	-45.61	55.000	-56.187
PACKB49	160.7	875.0	-1.40	374.958	2.356
Q3D	570.0	1593.	0.36	952.759	5.986
PACKC0U	1042.	1017.	0.47	1028.783	8.403
Q2F	1660.	467.9	0.32	881.520	4.985
Q1D	619.5	538.0	0.00	577.312	0.000
C0*	0.35	0.35	0.00		
Q1F	538.0	619.5	0.00	577.312	0.000
Q2D	467.9	1660.	0.30	881.522	4.575
PACKC0D	1017.	1042.	0.46	1028.784	8.326
Q3F	1593.	570.0	0.39	952.759	6.406
PACKC14	59.9	95.7	-43.20	55.169	-51.814
PACKC15	99.0	17.0	-84.02	4.276	-40.813

- Triplet spool 7.5 T-m/m skew quads can compensate *locally* for random roll angles  $\Phi$  of 2.5 mrad.

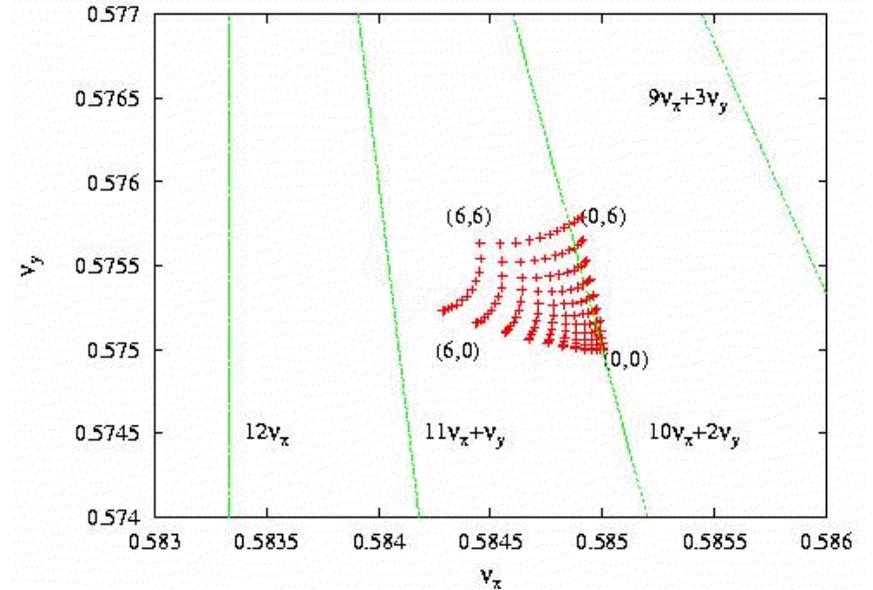
# Single Beam Tune Footprint

C0 IR



$$(\Delta v_x, \Delta v_y) = (8E-4, 8E-4)$$

Run II

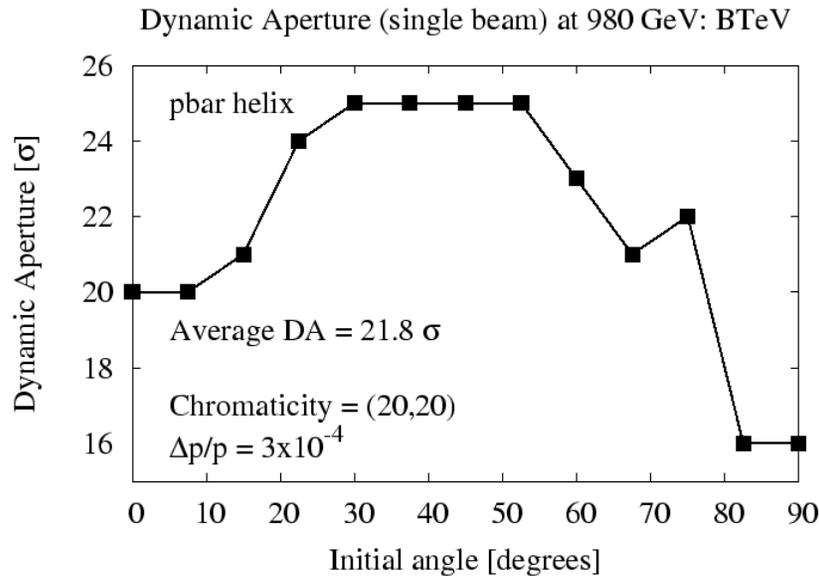


$$(\Delta v_x, \Delta v_y) = (6E-4, 6E-4)$$

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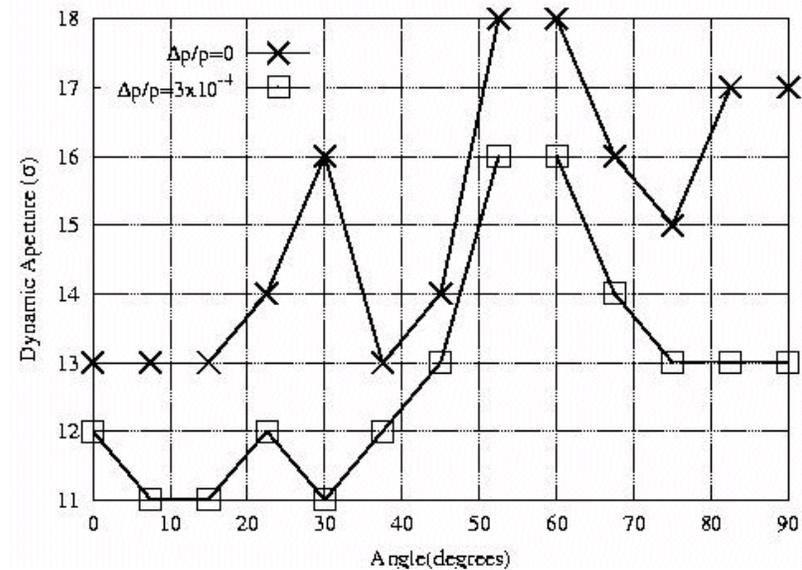
# Single Beam Dynamic Aperture

C0 IR



Average DA =  $22 \pm 3\sigma$

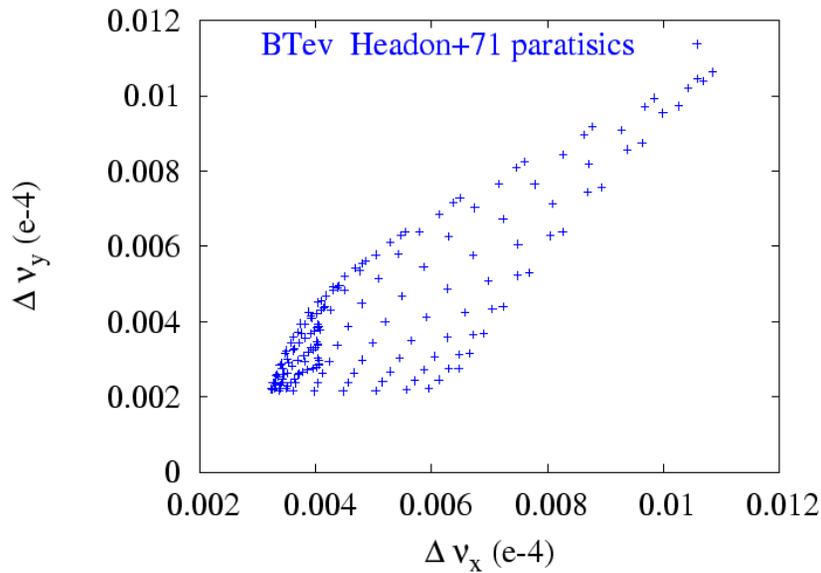
Run II



Average DA =  $13 \pm 2\sigma$

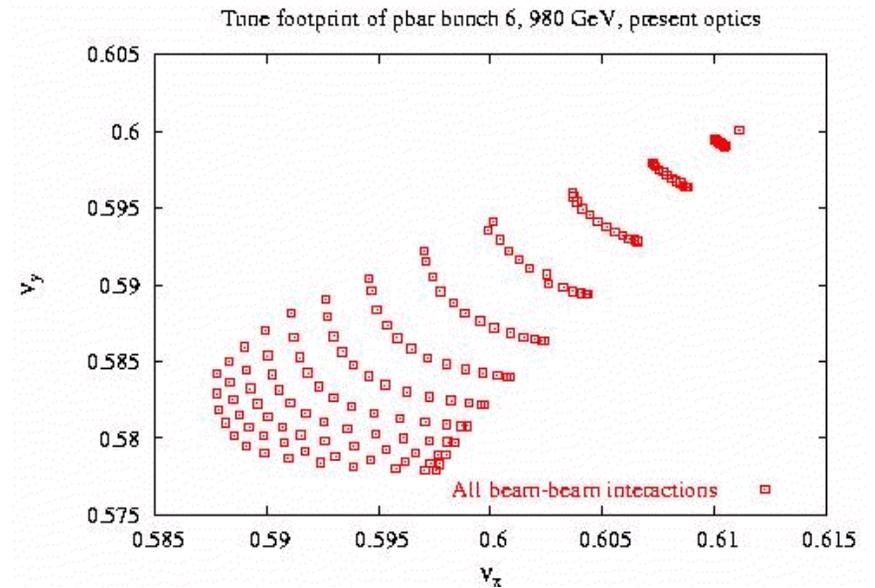
# Beam-Beam Tune Footprint

## C0 IR



$$(\Delta v_x, \Delta v_y) = (0.8E-2, 0.9E-2)$$

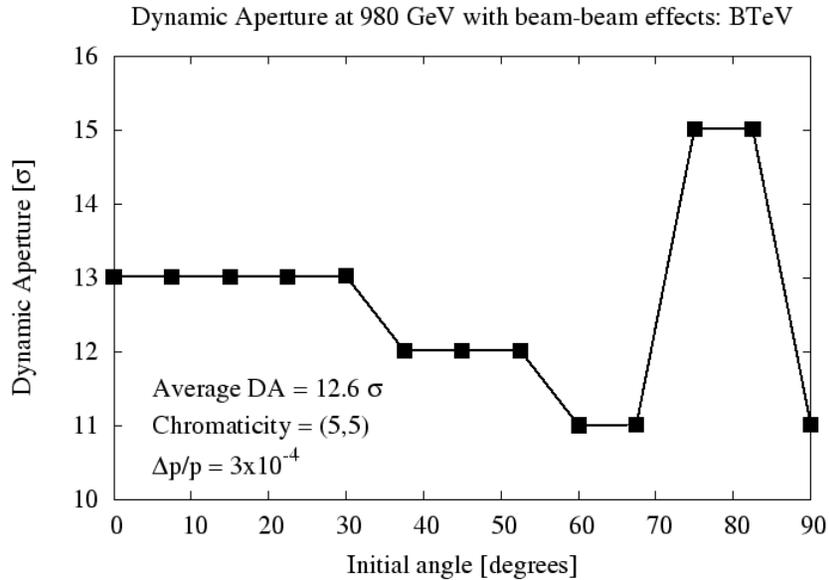
## Run II



$$(\Delta v_x, \Delta v_y) = (2.3E-2, 2.1E-2)$$

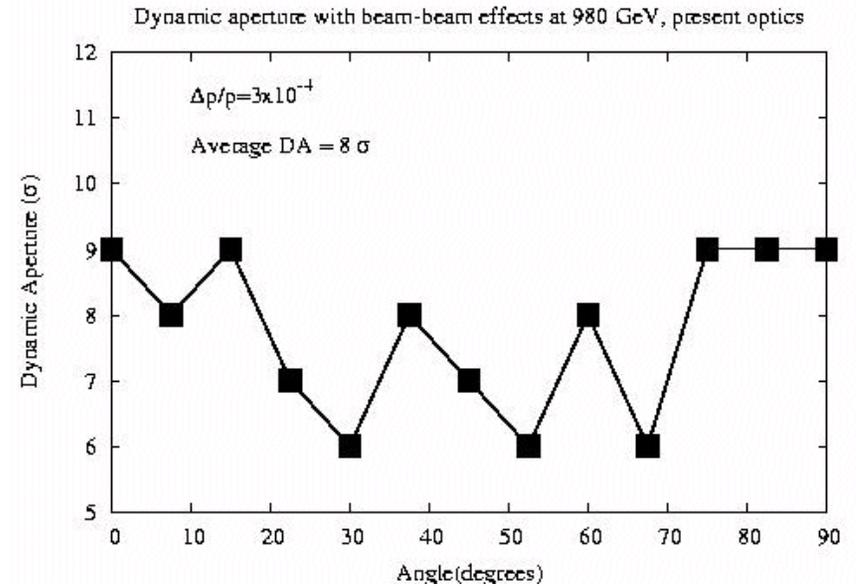
# Dynamic Aperture with Beam-Beam

## C0 IR



Average DA =  $13 \pm 1 \sigma$

## Run II



Average DA =  $8 \pm 1 \sigma$

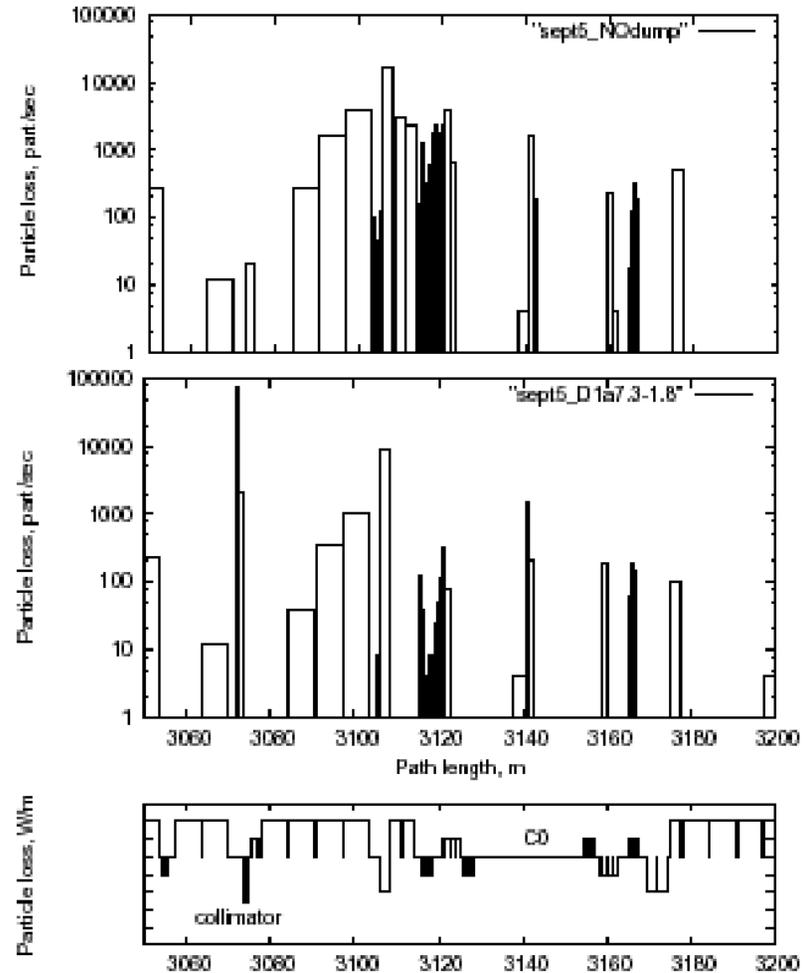
# Beam Halo & Collimation

- Existing Run II collimation:

Source	D0	B0	C0
Nuclear elastic beam-gas	8.8	8.0	9.4
Large angle Coulomb beam-gas	0.12	0.06	0.1
Tails from collimators	2.4	3.5	0.99
Elastic p-pbar at two IP's	0.144	0.105	-

- Installation of 1m collimator at B48 & 2m shielding wall on the proton side.
- Factor of 10 combined reduction in backgrounds.

Scenario	$n$	$h^\pm$	$e^\pm$	$\gamma$	$\mu^\pm$
No B48, no wall	24.2	14.5	58.9	1147	2.80
B48, no wall	11.0	9.29	42.4	730	1.81
B48, 2m wall	6.29	2.48	7.55	132	1.00



S. Drozhdin & N. Mokhov

## Ongoing AP Studies

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- Tune footprint & dynamic aperture studies continue
- Helix optimization & evolution from injection to collision
- Optimization & finalization of LHC magnetic lengths

## Summary

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- A stand-alone C0 IR has been designed for BTeV that reaches  $\beta^* = 0.35$  m using LHC quadrupoles in the final focus, and provides  $\pm 12.2$  m of detector space.
- The insert is optically transparent to the rest of the machine & has no impact on Run II nominal operating parameters.
- The IR design is mature, with further refinements being at the level of fine-tuning.

